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Presidential Address

By J. N. ALDINGTON, B.Sc., Ph.D., F.R.I.C., F.Inst.P. (*Fellow*)

New Horizons In Illuminating Engineering

In presenting to you this address on New Horizons in Illuminating Engineering I am very conscious of the honour which the Society has done me in electing me to the office of President for the forthcoming session and am grateful to the members and Council of the Society for the opportunity thus afforded to me of recording my firm convictions on a number of matters bearing on the future of illuminating engineering. In this Society a great deal of our work has its roots in much that is fundamental in other sciences. At the same time we have to remember, as Mr. Waldram so rightly reminded us last year, that our illuminating engineering is also affected by sensations beyond the scope of present science invoked by the specialised radiation which we know as light.

We thus see that unlike certain other cultural bodies whose members are concerned almost entirely with material things, in the Illuminating Engineering Society we have to deal not only with quantities which can be measured and qualities which can be assessed but also with effects which up to the present have defied measurement and which have proved incapable of description except in the most general terms. The science of photometry enables us to keep our feet on the ground, but the artist which lies somewhere deep down in us all causes us periodically to lift our heads and look at the stars. It is good that this should be so, but because of it we have to pay due regard to the importance of each aspect of the lighting task and seek to place in their perspective the tangible and the intangible which merge and mingle in our work.

From these broader considerations we must now concern ourselves with certain specific aspects of illuminating engineering and try to trace how the evolutionary process has controlled and governed developments in several branches of our work. For example, our sources of light are in the main incandescent solids or luminescent gases commensurate in dimensions with the lamps in use in the ancient world. The fluorescent lamp is a notable exception to this general thesis. Daylight, however, coming from the immense area of the illuminated sky lights up the visible scene with an effortless power which is both the envy and the objective of the illuminating engineer forced to utilise the available tools of his profession.

As we survey the enclosures which surround the light source both for its protection and for the re-direction of the emitted flux, we can trace the effect of progressive improvements in the efficiency of the fittings and in the effectiveness of the control. In the economic field, due largely to pressure from members of this Society and the recommendations of its Code of Practice, a more rational attitude towards expenditure on adequate lighting is being gradually attained but much remains to be done. In each of these fields our Society has the potentiality for providing the conditions which will inevitably reveal those new horizons for which all the work that has gone into the past has been but a preparation and a beginning.

Let us first of all consider the physical aspects which ultimately determine our ability to push back the frontiers of our art, our engineering and our science. We may aptly sub-divide our consideration into four main sections: the eye, the light source, the lighting fitting, and the economic factor. We shall consider these sections in turn, remembering that the first of them, the eye, governs in a fundamental manner the requirements of each of the others.

Presented at a meeting of the Society held in London on October 11, 1949.

The Eye

Not the least remarkable of the properties of the human eye is the comparatively narrow range of wave-lengths within which the visual stimulus is produced. Beyond 7,000 Å and below 4,000 Å, there is a negligible effect on the retina. Yet within these limits the eye responds to radiation and all the wonder and the beauty of vision become manifest. Through the phenomenon of the rainbow we can see the components of white light and something of their relative visibility, yet the infra-red and the ultra-violet radiation which are simultaneously emitted remain invisible.

This is a matter of considerable importance because in this Society we are primarily concerned with providing and using radiation which will enable men to see. We are only concerned in a very limited sense with radiation emitted in the regions outside the visible spectrum. We are, however, vitally interested in the knowledge which is being gained by studies of the behaviour of the eye in its differential response from the two thresholds mentioned above to the maximum of the visibility response curve at about 5550 Å. We are indebted to the physicists and physiologists who are studying the phenomena of vision and who are constantly throwing fresh light on many aspects of the eye's response to colour.

Great ingenuity has been displayed in the development and perfecting of electrical instruments which allow the eye to be dispensed with in much photometric and colorimetric work. We must not forget, however, that the human eye is the only instrument available to man capable of a full appraisal of the illuminated scene. In considering a limited section of our wide activities as an Illuminating Engineering Society and in calling for a measure of the luminous flux or the colour of an object in mathematical terms, we may sometimes overlook the limitations of any form of numerical assessment. Ultimately, however, our figures are no longer intelligible and we come face to face with the reality that only the eye computing, measuring and assessing all the facts in a moment of time can say whether our work is good.

Can figures describe the golden glow
Of a sunset, or measure its colour?
Can numbers portray the light's true play
Or co-ordinates tell of its splendour ?

The physical mechanism of the eye is capable of description in fairly exact terms. The functioning of its various parts have been revealed in the greatest detail. Studies of the physiology of vision are yielding results of the greatest importance to the illuminating engineer. But our grasp of the processes involved fails completely in the final stage in which man sees. The tangible physical mechanism gives place to the intangible mental response to the stimulus of the perceptory nerves. In the last analysis it is this aspect of vision which is perhaps the most important of all and which we must ever keep before us as a subject for continuous study and as one of the new horizons which we seek to comprehend.

I will conclude this section by quoting from a publication of one of the founders and Past-Presidents of this Society, Sir John Parsons, who in 1932 in his " Discussion on Vision " made the statement that " It is the custom . . . for the physicist to attack his problems by a process of analysis and simplication. Hence it behoves him to remember what the biologist is less likely to overlook, namely, that animal behaviour is the response to the situation as a whole, which can in no case be split up into fragments without profoundly modifying both the whole and the parts."

Light Sources

As we turn now to sources of light we are at first perhaps impressed by the apparent complexity of the present position. Early lamps such as the candle and the oil lamp, the wax taper and the carbon filament lamp are still produced in large

quantities, notwithstanding the fact that they have been largely superseded by more efficient or more appropriate types. While it is true that many designs which played a not unimportant part in the evolutionary process have since been discarded the number which have been retained is quite remarkable.

I want us to consider some of the factors which have led to this state of affairs. Among these not the least important has been the search for more efficient means of producing light. I hope that I may be forgiven if I concern myself in this section practically exclusively with the production of light by the conversion of electrical energy.

It can be shown that the dissipation of one watt would produce 621 lumens if the radiation was emitted entirely at the peak of the visibility curve, i.e., at about 5,550 Å. If, on the other hand, the radiation produced by the conversion of electrical energy lay wholly within the visible spectrum and with approxiately the same energy distribution as that in sunlight the efficiency would be about 220 lm./w. Let me say here that no one has yet conceived of a means by which such a conversion could be achieved.

There is, however, a wide gap between the efficiency of existing light sources and these theoretical maxima. In the case of tungsten filament incandescent lamps the average attainable efficiency for a given lamp type is determined by such factors as the allowable temperature of the filament, unavoidable energy losses at the electrodes and filament supports, the designed life of the lamp based upon the known rate of evaporation of tungsten for a given temperature, thermal losses from the filament by a variety of means as well as by surface differences along the length of the filament and minute variations in the geometry of the filament coil.

As a result of the interplay of all these and other factors the maximum efficiency at which a practical tungsten filament lamp can be made to give a reasonable life of, say, 50 hours is about 30 lm./w. for a very high wattage type. This value should be compared with efficiencies of some 10 to 15 lm./w. for a 1,000-hour lamp of domestic type and size.

It is necessary to consider these figures against a back ground of the maximum theoretical efficiency for an incandescent tungsten wire. At the melting point of the element, i.e., at about 3,655 deg. K an efficiency of about 50 lm./w. would be obtained, but as at this temperature the element would be passing from the solid into the liquid phase the life of the device would be zero. In the design of any practical form of lamp, therefore, we must arrange for a filament temperature materially less than the melting point and the lamp must be operated under conditions such that the melting point is never attained. At the high temperatures at which the filament operates the rate of evaporation of tungsten from the surface of a thin wire is quite high and means have to be found for reducing or suppressing this evaporation. As is well known, reduction in the evaporation rate is obtained in the ordinary gas-filled lamp by the introduction of argon or nitrogen, or in some cases krypton.

Even with the most compact filament form yet devised, these gases occasion material additional thermal losses and recourse must therefore be had to coiling the filament to allow a net gain in efficiency to be achieved for a given life. To obtain still higher efficiencies measures that suggest themselves are the use of gasfillings of xenon with its very low thermal conductivity or high pressure mercury vapour. For certain reasons a combination of these two atmospheres would be desirable. At the present time, however, there are very serious economic as well as technical restrictions against such a proposal, not the least of which would be the quite prohibitive price of the extremely rare gas xenon. Experimentally, however, some very interesting data might be obtained by an investigation covering the limiting conditions I have mentioned.

In the meantime it is interesting to note that each of the four historic types of tungsten filament lamp are still being manufactured, namely, the cage filament and the

coiled filament vacuum lamps, and the single coil and coiled coil gasfilled lamps. There are notable differences in the luminous and performance characteristics of each of these types, but it would undoubtedly be of ultimate advantage to both the manufacturer and the user if the number could be reduced. It would appear, therefore, that there is a need for a single lamp type which will combine the advantages of each of the earlier forms. There is thus scope for development in the incandescent lamp field in a direction which is often regarded as having reached finality.

The position is somewhat different when we consider the electric discharge lamp in its many and varied forms. We are in the midst of a rapid evolutionary process and it is necessary to try to stand back and view this process from afar in order to obtain some measure of true perspective.

In the years before 1930, and indeed to an even greater extent since that date, many elements were investigated to determine their suitability as light sources when excited by the electric discharge. Many of these showed interesting properties. Some were eliminated as unsuitable at quite an early stage, while others were investigated with greater thoroughness.

In the earliest electric discharge lamps the rare gases, together with nitrogen and carbon dioxide appeared most promising, but the efficiency was low. Of the metals those of the alkali group held out some promise, and caesium and sodium received the most attention. The white light from caesium was very attractive, but the extreme reactivity of this metal has so far prevented its use except in certain experimental lamps. The difficulties with sodium were, however overcome some 20 years or so ago, and the resonance radiation from this element provides a virtually monochromatic source of high efficiency.

Of the other metals mercury occupies a unique position largely because at normal temperatures it exists in the liquid phase and therefore can be used to develop high pressures at temperatures which can be readily attained in glass or quartz vessels. The possibilities with mercury have, therefore, been examined over a wide range of operating conditions, and a number of distinct lamp types have emerged, each of them of value in some particular field of usage.

No other substance is known likely to supersede mercury as the principal element in metal vapour discharge lamps. This statement may appear far reaching, but it is made with due regard to other factors such as the possibility of producing new transparent refractories capable of operating at much higher temperatures than are at present possible. If the time comes when vitreous envelopes can be made through which current-carrying leads can be sealed hermetically and which can be operated continuously at temperatures of say 2,000 deg. C., then a new horizon in discharge lamp developments could be envisaged, but the time is not yet.

There are some reasons for believing that ultimately an efficiency of perhaps 75 lm./w. might be achieved in a practical lamp by the electrical excitation of mercury vapour. It is interesting to note that this value is of the same order as that apparently possible with electrically excited sodium vapour, although the quality of the radiation in the two types is widely different. In both cases, however, the high efficiency is bound up with the high percentage of luminous flux lying in the centre regions of the visible spectrum to which the eye is most sensitive. Whether these values are approaching the maximum for the efficiency of a plain electric discharge lamp, it is as yet not possible to state with certainty, but there are indications that this is so.

At the present time the electric discharge lamp finds its greatest usefulness for those purposes where the efficiency of light production is the primary consideration and where the colour of the radiation is of secondary importance. It cannot be too strongly emphasised that any general improvement in the colour of a given light source is only obtained with some reduction in efficiency. This follows naturally from the fact that improvement in the colour entails a redistribution of the radiant

energy in the visible spectrum, and if the bulk of the radiation is being emitted in the region of maximum eye sensitivity, redistribution entails a loss of luminous efficiency, although not necessarily a loss in the efficiency of energy conversion.

New possibilities in the electric discharge lamp field have been opened up by recent investigations of the heavier rare gases, namely krypton and xenon. Under certain conditions of excitation efficiencies as high as 40 lm./w. can be obtained with a spectrum not dissimilar from that of an incandescent radiator at some 6,000 to 7,000 deg. K. It is too early to say whether investigations in this field will result in practical forms of lamp capable of more general usage than the specialised types so far developed.

The third main class of light source to which I would seek to direct your attention is that of the fluorescent lamp. As you know the primary radiation is provided by the low-pressure mercury discharge, although the radiations from many other electrically excited elements and compounds have been investigated. The preference for mercury vapour rests on the favourable position occupied by its resonance radiation in relation to the excitation wave-length required by modern fluorescent compounds.

While this relationship is by no means only a fortunate act of nature, it is still a matter for satisfaction that it has been found relatively easy to convert up to 60 per cent. of the energy of a low-pressure mercury discharge tube into radiation at 2,537 Å. and that this wave-length is most effective in exciting to fluorescence a large number of inorganic chemical compounds.

Naturally occurring substances have served as beacons to light the way for much fundamental research on the synthesis of phosphors, but the man-made materials greatly exceed in efficiency and excel in variety of colour the products of nature, and it has been found possible to produce a host of compounds not met with in the natural state.

The production of light by utilising the phenomenon of fluorescence has its own limitations. The very act of converting the ultra-violet radiation from mercury into light of daylight quality involves an energy transformation with an efficiency of not more than 50 per cent. In addition to this initial loss we have to take into account the fact that in a fluorescent lamp itself only about 60 per cent. of the electrical energy appears as resonance radiation from the mercury atom, and therefore from an energy point of view the overall efficiency of transformation is the product of these two figures, i.e., about 30 per cent. If we now apply this percentage to the theoretical value of 220 lm./w. for the conversion of electrical energy into white light, we can envisage a probable maximum efficiency for the low-pressure fluorescent lamp producing light of daylight quality of about $220 \times 30/100 = 66$ lm./w. I am sure it will be of interest to the Society to know that already with the new phosphors developed in this country we are approaching this maximum. Here again, therefore, it is unlikely that material increases in the efficiency of the low-pressure mercury fluorescent lamp will be obtained in the future without some sacrifice in the colour-rendering properties of the light source.

From many different aspects of light source development, therefore, we are impelled to the belief that using existing techniques we are already approaching limiting values of efficiency. It may well be that the horizons are those imposed by nature and not by lack of vision or skill.

While this appears to be true, I am sure that it will in no sense be a deterrent to those who spend their lives in seeking for more efficient ways of producing light. At the same time there is the need to concern ourselves increasingly with methods for improving the uniformity of our light sources and their performance characteristics, and on the application side with making the maximum possible use of the flux produced by the source.

In all this I must not fail to try to impress upon you the importance of each

individual contribution, however small. Practically every development in the lighting field has been dependent upon the effort of a host of previous workers who while themselves unknown have paved the way for each major forward step. It has perhaps not been given to them to be able out of a welter of ideas to grasp the ultimate solution. The joy of having produced some major step forward may never have been theirs, yet without their contributions and their painstaking work the way would not have been prepared for a new horizon to be glimpsed.

Remembering this it behoves us as a Society who meet with the object of promoting discussions in every branch of illuminating engineering to provide increased opportunities for the reading of papers on original subjects and for that free exchange of ideas which will produce the atmosphere in which the individuality of our members can develop and thrive. We must encourage our younger men by all the means we can command.

We shall be making a major contribution to the enlargement of the objects for which this Society was founded if our association together, both in London and in our Centres and Groups, creates and promotes those conditions which will stimulate the free interchange of ideas and an atmosphere in which all of us may be enabled to develop our latent powers. We must ever strive for the advancement of the art and not of the individual.

It is perhaps not inappropriate to mention here that the official journal of the Society, LIGHT AND LIGHTING, offers opportunities for short articles and technical contributions which do not aspire perhaps to the standards required by the Society's transactions but which, nevertheless, are of a type likely to be of general interest or of educational value. I am sure that great benefit will accrue to us if more members of the Society will take advantage of the opportunities which are thus available to them.

The Lighting Fitting

It is to be regretted that some more appropriate term than lighting fitting has not found its way into common usage in this country. It is, of course, well understood that the term includes the complete device which supports or houses the light source, serves for its physical protection—if protection is needed—and includes optical members for controlling the light emission. In its simplest form the lighting fitting may be little more than a lamp holder with an upper element to redirect some of the light in a downward direction. It may, however, be a very complex affair including both reflector and refractor systems as well as providing a cover for the lamp and any other associated equipment necessary for its proper functioning.

Ideally a lighting fitting should seek to utilise and make effective the maximum possible percentage of the emitted flux. Unfortunately it is often only too true that many devices fall far short of this ideal.

Quite often our light sources, on which so much care has been expended to gain the maximum possible luminous efficiency, are surrounded by or enclosed in fittings which have been designed with little or no attention to the lighting task which they have to serve. We are all, I am sure, anxious that art should play its proper part in fittings design but in the majority of cases, and most certainly in connection with domestic lighting, the functional aspects of fittings design should be dominant and line and form should be used to give a pleasing appearance, while the use of unsuitable materials or heavy decorations should be deprecated by the members of this Society.

With earlier sources of light the fitting was little more than a protective or functional device. In early oil lamps for example it consisted of a receptacle for the oil fuel and a holder for the wick. Later, however, it was found that the introduction of a glass chimney could so modify the draught of air that the intensity of the oil flame was increased many times. Apart from modifying the shape of the flame,

however, the glass chimney did little or nothing to redirect the light in wanted directions.

In the case of the early gas lamp the chief function of the lighting fitting was protective. Whether glass or other transparent material was used its primary function was to prevent interference with the flame by air currents or to afford actual protection from the weather where the gas lamp was used for outdoor illumination. At a later stage devices were introduced to assist in the redirection of the emitted light. A considerable step forward was made when the vertical type mantle, designed to fit the shape of a bunsen flame, was superseded by the inverted mantle, which had a naturally improved light distribution. Not only was this so but the inverted mantle lent itself more readily to utilisation in improved lighting fittings.

Progress since the advent of the inverted mantle has been rapid and efficient lighting fittings for interior illumination, for street lighting, and for floodlighting have been evolved. The development of the high-pressure gas-lighting units brought about an increase in the brightness of the mantle and allowed for the projection of the light over considerable distances in accordance with modern street lighting techniques. It is interesting to note how, with the widely different types of source produced by the combustion of coal-gas or the consumption of electrical energy, lighting fitting designs have run along closely parallel lines.

An examination of the history of domestic lighting by means of the electric lamp reveals some very interesting facts. In the first instance electric lamps were capped in such a way that they could be screwed directly into gas-brackets to replace the bats-wing burner. At a somewhat later stage multi-light fittings were evolved, chiefly characterised by the use of complex ornamental brackets to support either bare lamp bulbs or lamp bulbs decorated by fluted or plain glass covers.

The next stage was the introduction of a dish-like fitting, open at the top and so arranged in relation to either a single lamp bulb or a cluster of smaller bulbs, that the light source was not visible from any normal position in the room. A proportion of the light was transmitted by the bowl and additional illumination resulted from diffuse reflection from the ceiling and upper regions of the walls.

It appears that, in many cases, the chief emphasis with this type of fitting was on the decorative angle and too limited attention appears to have been paid to the overall efficiency.

Further studies of the properties of illuminating glassware led to considerable improvements and increased diffusivity and transmission were obtained simultaneously. The present position, however, gives us no call for complacency while it is possible to find on the market lighting fittings made from unsuitable materials and in the design of which little regard appears to have been paid to the primary performance of the fitting which is to diffuse and distribute the light and not to absorb it.

In considering this matter we have of course to remember that the fluorescent lamp with its widely different geometry and brightness brings into the domestic lighting field a potential rival to the tungsten filament lamp. From an illuminating engineering point of view its introduction for domestic lighting purposes may well be a matter of primary importance. It may indeed mark another new horizon beyond that which at present limits our field of vision. Just as the introduction of the high-pressure mercury vapour lamp brought about a revolution in the technique of street lighting some fifteen years ago so will it be possible for the fluorescent lamp to bring about a new era in the domestic lighting field.

In the majority of the homes in this country we have tolerated for too long lighting which is inadequate with regard to the position of the light source, its brightness within the field of vision and the inadequacy of the illumination at the working plane. It is often not appreciated by the general public that in the home there is a great deal of work carried on of a type which requires the maximum possible acuity of vision.

fine crocheting, needlework and the more commonplace darning of articles of clothing come readily to mind as examples of work requiring close vision and good lighting. Too often is room lighting in the home dependent upon a single ill-placed lamp with a luminous output entirely inadequate for satisfactory seeing. We are very conscious of this when we consider how many millions of words of newsprint are read daily under artificial lighting.

I would, therefore, made a plea for a very special study of this problem and for a bold attempt to re-educate public authorities, builders, architects and people generally to the benefits which will result from an entirely different approach to the question of home lighting. There is too much complacency in regard to these matters.

Great improvements can be brought about by the use of more lighting points, the use of lamps of higher wattage and by the proper placing of suitable lighting fittings. With the fluorescent lamp, which is virtually only just at the point of being introduced into the domestic lighting field, it is of the first importance that the members of this Society should lead the way in showing how it can best be used and in preventing its misuse—the challenge is unmistakeable.

When we consider the present municipal housing programmes and realise that in the majority of cases the lighting in these houses is still being done by the traditional method of hanging one or in some cases two lighting points in each room and leaving to the tenant the addition of some ornamental fitting we can appreciate how little advance has been made in the last decade or two in this important field of illuminating engineering.

We shall be doing wrong if having realised the need we do not press for new standards of home lighting. It is surely just as important that the homes of the people should be effectively served by our Society as it is important that our great public buildings and factories should have properly designed lighting installations.

We must turn now very briefly to outdoor lighting. For all practical purposes exterior lighting in this country is confined at the present time to street lighting, and there are some features of considerable interest in the early history of the art. In the fifteenth century it was made mandatory on householders in the City of London to display a lantern outside their premises to assist the wayfarer to avoid the pools of water and other obstructions which no doubt would interrupt the free passage of pedestrians in those early days. One can well imagine that the lighting conditions which would result from the observance or lack of observance of this mandate would hardly conform to the standards for street lighting which are now considered appropriate !

With the advent of coal gas and the electric arc the possibilities for street lighting were vastly improved. In general, however, it was only possible for the engineers of the day to arrange for isolated lighting points at some considerable distance apart, the light distribution being largely dependent on the natural properties of the source. It is not necessary for the purpose of this review to try to place an exact datum when street lighting fittings of modern type began to be used in quantity in this country. Sufficient it is to say that for several decades there have been available reflector and refractor type fittings designed to modify the natural light distribution of the source and to utilise it in a more efficient manner for the illumination of the road surfaces and the surrounds.

The interim report of the Ministry of Transport Street Lighting Committee presented in 1935 and the final report of 1937 recommended lantern mounting heights and details of spacing and positioning for various classes of road illumination. The result was a gradual transformation in the effectiveness of street lighting in this country. While these improvements were to some extent brought about as a result of the development of new light sources their implications affected all types of street lighting

equipment including those using coal gas and fittings designed for incandescent filament lamps.

At the present time for a variety of reasons no great extension of street lighting facilities is possible and therein lies our opportunity. In any enterprise where there is a big demand it is difficult to deflect the course of production into new channels, but when for any reason there is a lull or a lessening in the productive need then is the time to take stock, to work with new vision and to seek a new horizon. As members will recall the recent development of the use of fluorescent lamps for street lighting occurred at a time when little or no new installations were possible.

There are many different lamp and lantern combinations used for street lighting—indicative among other things of that restless seeking for improvement from which I am sure a more perfect solution will eventually emerge. We can assist in stimulating thought on this matter by arranging that discussions on street lighting techniques continue to feature largely in the work of our Society.

In concluding this section and after studying the disastrous effect on visual acuity of glaring or badly adjusted headlamps on motor vehicles, I am of the opinion that it may become necessary for public authorities to insist that headlamps must not be used when the motorist is on a traffic route at night illuminated to modern standards. It will, I am sure, be agreed by all that the continued use of headlamps in a well-illuminated road is of little or no benefit to the driver of the vehicle carrying the lamps, but it may cause such a serious loss of effective vision to other road users facing the headlamps as to be a positive menace to public safety. We may, therefore, be approaching the time when in the general interest the use of headlamps should be forbidden on illuminated thoroughfares.

It is significant that in the final report of the Departmental Committee on Street Lighting, published in August, 1937, Group "A" traffic routes are described as "roads on which the standard of lighting should provide an ample margin of safety for all road users, without the use of headlights by motor vehicles." Twelve years after the publication of that report we still find that many drivers of motor vehicles continue to drive through well-lighted streets with blazing headlights to the discomfort and even the danger of other road users.

We can learn much from the fact that in the absence of any glaring source in the field of view a very low level of even illumination will provide safe and satisfactory seeing conditions for the drivers of motor vehicles and for other road users. It is instructive to contemplate a country road illuminated only by the skylight at the time of the full moon.

The Economic Factor

We must turn now to the economic factor and examine its influence on good lighting practice. Whether we are considering the illumination of domestic premises, commercial establishments, industrial buildings, or streets and highways, we find that in general it is not possible to produce the optimum illumination either from the point of view of quality or quantity due to the limitations imposed by considerations of economy. In every scheme the final effect is achieved as a result of compromise.

What, then, should be our attitude to this state of affairs? The members of this Society include in their number representatives of many branches of human endeavour. We have the industrialist who has to determine the extent to which expenditure can be incurred on improving lighting in his factories. We have representatives of public authorities who are forced to budget very closely for each and every one of their projects. Most of us are householders who know from personal experience the difficulty of having all that we would like, and we have the practising lighting engineer whose

schemes are often modified and sometimes stultified by budgetary cuts in lighting expenditure.

At the same time as a Society we are responsible for the maintenance and improvement of the Illuminating Engineering Society Code of Practice, which gives minimum values of illumination for visual lighting tasks. While recognising the impact of the economic factor we must not hesitate to press for a proper appreciation of the importance and urgency of improving lighting standards. I can say without hesitation that it is hardly possible to visualise conditions in which too much light can be provided for general illumination.

Conclusion

As I take up this office I am, I hope, in a position to view these matters with some degree of impartiality. We are concerned with fostering and furthering the aims of those who founded the Society and our continued well-being is largely dependent upon the manner in which we discharge our task. To those who offer papers to be read at our sessional meetings in London and in the great towns and cities where we have centres I would suggest that wherever possible more attention should be paid to the wide diversity of interest of those who constitute our membership. A statement which will appear an obvious truism to those with a specialised knowledge may require more detailed explanation and, if possible, demonstration to drive home its truth to other groups of our members. There can be no doubt that the objects and aims of our Society are based upon the broadest of humanitarian considerations. There can be few branches of human endeavour which offer possibilities of contributing more to human happiness than the work of the illuminating engineer. To provide light where before there was darkness, to enable men and women and little children to preserve their gift of eyesight unimpaired, to add a little beauty to the lives of one's fellow men—this surely is enough.

Register of Lighting Engineers

The Council have accepted the following applications for inclusion on the Register of Lighting Engineers:—

T. M. Christie
G. Dixon
R. A Eshelby
R. H. Hall
A. W. Jervis
E. C. Lennox
A. H. Nash
R. W. W. Ormerod
C. Stuart.
W. G. Whitaker.

On Age and Illumination in Relation to Visual Performance

By H. C. WESTON *(Fellow)*

Summary

A number of male subjects whose age distribution was within the range 19-47 years, and who were all able to read J.I., were given tasks visually comparable to various practical forms of "close work." The performances recorded at different illuminations, ranging from 0.5 lm./ft.^{2} to 512 lm./ft.^{2}, are analysed to show the effect of advancing age. It is shown that performances of each of the visual tasks declines from early adulthood, whatever the illumination. The effect of varying illumination over the range studied increases as age does, and also as the size of detail and the contrast in the work is reduced. It appears that equal performance by the youngest and oldest subjects is possible only if the young are handicapped by low illumination. The decline observed is discussed with reference to other findings for persons of similar age distribution. The paper shows the importance of providing high illumination for "middle-aged" persons doing fine work, but attention is also drawn to the apparently greater effectiveness of suitable optical aids.

In a previous paper (1) some results of visual performance tests applied to a number of persons were presented to show how they vary with the age of the subjects, the illumination used, and the size of the detail to be discerned. The object of the present paper is to give further observations showing the variation of visual performance with age; to consider these observations in relation to the problem of suitable standards of illumination; and to discuss the observations in the light of others concerning somatic ageing, particularly ageing of the visual system.

The scientific study of the change in human capacities with age has not been commensurate with the importance and interest of the subject. Indeed, until quite recently, it seems to have been pursued almost alone by Quetelet (1835) and by Galton 50 years later. Of course, many acute observers have described the course of human ageing in qualitative terms and some of these descriptions are of great antiquity. But a metrical life history of our capacities is not easy to make. Two methods of investigation are possible though not equally practicable. The method adopted hitherto consists in measuring selected capacities in more or less representative age-differing samples of the population, so obtaining data from *different groups of individuals at the same time*. The other, and far more difficult method to follow, is measurement of *the same groups of individuals at different times* as each advances in age. It is from serial measurements that the true variation of capacities with age is to be discovered, but no single investigator can make them for the whole ordinary span of life. The measurements discussed in this paper include some obtained simultaneously from differently aged persons and also repeat measurements relating to the same persons when each of them had aged by five years.

The Subjects

Records of visual performance, using experimental tasks, were obtained from twelve subjects, all of whom were members of the scientific staff at the National Physical Laboratory. The experiments were not undertaken with the object of ascertaining the variation of visual performance with age, and the subjects were not selected for this purpose and were unaware that their performances might be compared on this basis. It happened, however, that they were fairly evenly distributed

by age in the five consecutive quinqueniads or semi-decades covering, approximately, the middle third of the normal span of life. So, the results obtained could be analysed to compare the performances of five small differently aged groups, three of which contained two subjects and two of which contained three subjects. Although these numbers are very small, it will become apparent that consistent group differences of performance were observed.

Particulars of the refraction of each subject are given in the previous paper referred to and need not be repeated here. Individual errors of refraction were corrected and no difference in this respect then remained between the groups which seems at all adequate to account for their differences of performance. With correcting glasses as required, far vision was closely similar for each group. None of the subjects had vision less than 6/6 in the best eye nor less than 6/12 in the other eye. Four subjects required an additional correction for near work, and every subject, when wearing any glasses worn during the experiments, could read the J.I. test-type for near vision. It may be noted that, in accordance with the usual clinical practice, the subjects were not timed in reading either the Snellen letter chart or the Jaeger near vision test print. The ocular muscle balance of each subject was tested and only one, a myope corrected to V = 6/6, was found to have an imbalance in near vision greater than the amount usually regarded as physiological.

The Visual Tasks

The visual tasks performed by the subjects involved the perception of small detail in test-objects situated approximately 13 inches from the eyes (ordinary reading distance). The test-objects were Landolt's broken rings, printed as shown in Fig. 1, and the successive rows of these were scanned from left to right as in ordinary reading. On any one test-sheet the rings differed among themselves only in the orientation of the gap for which there were eight possible positions. All the rings had to be examined so as to find those having the gap in a particular position, and this position was prescribed immediately before each test was made. Because the effect of three variables, viz., size, contrast and brightness, was to be investigated, there were 72 different visual tasks and each of these was performed twice by each subject. The total of 72 is given by 3 sizes × 4 contrasts × 6 illuminations. The three sizes of gap were 4.5 min., 3 min., and 1.5 min., and, of these, the intermediate one corresponds approximately to the size of detail in the news columns of the daily press. The four contrasts, or values of relative brightness difference of paper and print, were 0.97, 0.56, 0.39, and 0.28, these being obtained by printing the rings black on some sheets and grey on others. The six illuminations ranged from 0.5 1m/ft^2 to 512 1m/ft^2 by equal ratio steps of × 4. The illuminations were obtained without the light sources being visible to the subjects, and the brightness of the general field of view was maintained at a value not less than half that of the local field of attention. Though tasks of the kind described are "artificial," they resemble many practical tasks in their demands upon visual capacities.

An unusual and, for the present purpose, a very fortunate circumstance, is that similar visual performance tests were done under similar illuminations by the same subjects on occasions separated by a time interval of five years. So it is not only possible to compare the performances of the five differently aged groups, but also to observe the effect of an advance in age of five years upon each group's performance.

Since, then, the difference of the performances of two groups who are differentiated in age by a semi-decade, but who cannot be known not to differ in any other relevant characteristic, can be checked against the difference of the performances of the younger of these groups at the beginning and end of the same semi-decade of the life time-scale, it is possible to estimate the magnitude of any effect of advancing age

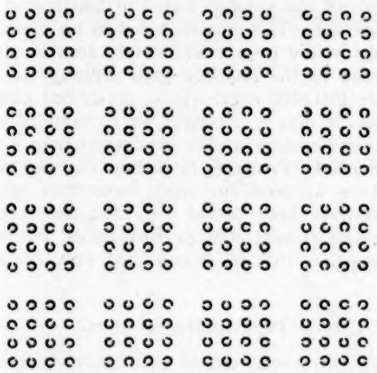

Fig. 1. Arrangement of the Landolt rings to be inspected.

with greater confidence than evidence drawn only from differently constituted groups would allow. For example, if the performance of C, whose age is 25 years, is found to be lower than that of B, whose age is 20 years, this may be due partly (or even wholly) to some difference other than age between C and B: but, if it is also found that when B has advanced in age to 25 his performance has declined to about the level of C's at age 25, we can be much more confident in attributing the performance-difference of B and C to their age-difference than we could be otherwise.

The Measure of Visual Performance

The visual performance of each experimental task was found in the following way. The subjects were asked to indicate all the prescribed rings they saw by cancelling them with a stroke of the pencil. Their work was timed and the number of prescribed rings cancelled was counted so that the time per ring could be found. This time includes that required for the act of cancelling the ring and so cannot be used for deriving the rate of *visual* performance only. The two components of the time per ring, that is, the visual discrimination time and the indicator action time, cannot be separately measured; hence, an exact determination of the discrimination time is impossible, though, by a suitable technique, it can be ascertained approximately. The method adopted was to time the subjects while they worked through a test diagram in which all the prescribed rings had been made extremely conspicuous by filling them in with red ink so as to convert them to red spots. The search time was thus minimised, and the time taken per spot cancelled could be regarded as almost entirely action or indicator time. This time was then deducted from the gross time per ring found for each subject when doing the ordinary visual tasks, and the net time so found is the closest practicable approximation to the actual discrimination time. Even this, however, is not a suitable measure of performance, for it takes no account of any mistakes a subject may make. The mistakes made were almost entirely oversights, that is to say, subjects sometimes failed to observe some of the rings they should have cancelled. The total number of rings which should have been cancelled by each subject in each test was counted, and the number actually cancelled then expressed as a fraction of the total. This fraction is a measure of accuracy, and, if the net discrimination time per ring is divided by it, a corrected time is obtained which may be regarded as the time that would have been required for an accurate performance: the reciprocal of this is the index of visual performance used in this paper.

With the most difficult visual tasks, i.e., those involving the smallest size, poor

contrast and low brightness, one or two of the subjects failed to find any of the prescribed rings in the time allowed for the test. This was recorded as no score, but this does not necessarily mean that the gaps in the rings could not be seen at all. Three events are possible, (a) no discrimination of the required gaps although the number of rings examined in the time available included some of the prescribed kind, (b) no discrimination of the required gaps because only a few rings were examined and these were rings having the gaps not in the given direction, and (c) no correct rings were found but one or more wrong rings were cancelled. Probably (a) means that the task could not be done even if more time had been allowed, (b) might mean that, given more time, some of the correct rings could have been found, i.e., that the experimental technique did not permit the measurement of very slow performances, and (c) means that the subject's performance was negative, that is, it consisted only of oversights and misperceptions.

Discussion of Group Performances

For each age-group, the average performance scored with each visual task was found. Graphs of performance v. illumination for each task of different size and contrast were then prepared for each group. As would be expected, owing to the small number of observations obtained at each level of illumination, the points plotted did not lie upon smooth curves, though definite trends were obvious. Allowing for unquestionably exceptional scores, smooth curves were fitted to the plots, and performance values derived from these curves have been used in preparing Figs. 2, 3 and 4. These diagrams relate to 18 of the visual tasks (3 sizes × 1 contrast × 6 brightnesses) and show how the performance of each group changed when its members advanced five years in age, as well as how performance varied from group to group on both occasions

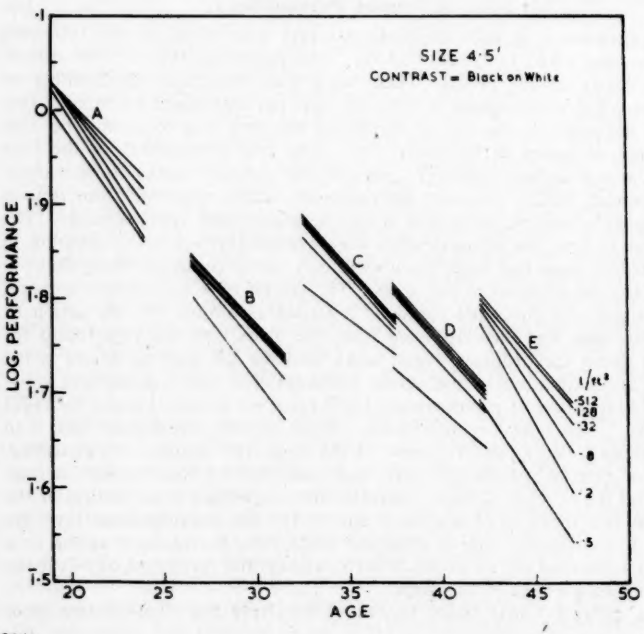

Fig. 2. Diagram showing the decline in performance of persons of five age-groups for an advance in age of five years. The decline is shown for six levels of illumination, the size of detail being 4.5 mins. and the contrast black/white.

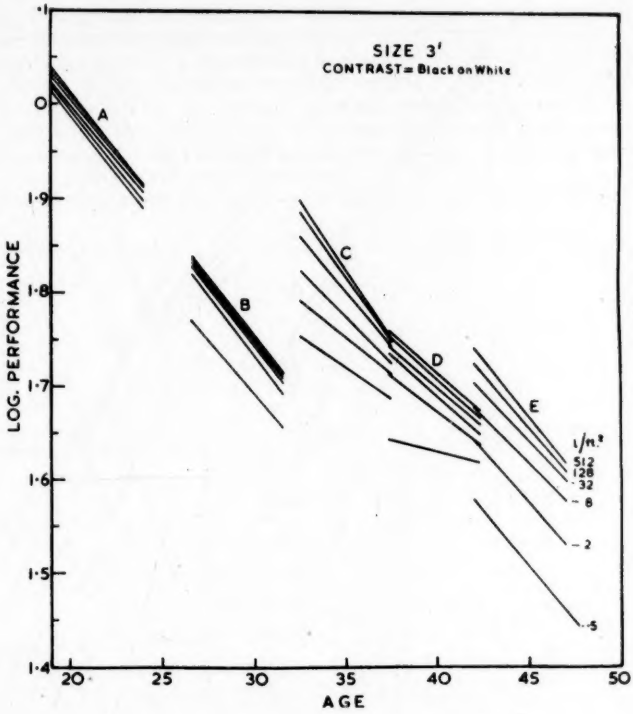

Fig. 3. As Fig. 2, but for tasks involving a size of 3 mins.

(five years apart) when it was measured. Actually, the diagrams are plots of log. performance against age. By using a scale of logarithms, a point representing any value of performance is distanced vertically from that of any other value according to the *ratio* and not the difference of the values; therefore, the ratio between any pair of values considered is the same as that of any other pair whose points are separated vertically by an equal distance, although the one pair may be of high values while the other is a pair of low values. One advantage of this method is that it is easy to see from the graphs whether the effect of varying the illumination over the range indicated is proportionally the same, or is greater or less, at one age than it is at another; but this is not so with a plot to an arithmetic scale, since the linear spread of the points representing a range of low performance values is less than that of the points representing an equal range of high values.

In Figs. 2, 3 and 4, lines are drawn between each pair of points representing chronologically different performances of each group with a particular illumination. All these lines slope downward, so it is clear that in growing older by five years each group's performance declines, and the decline is evident at all values of illumination.

For the 4.5-min. and 3-min. tasks, the slope of the lines does not show any consistent variation of the *rate* of decline with illumination, nor with the group age, though with the most difficult task (Fig. 4) there is some indication that the rate of decline varies inversely with illumination within certain limits of the latter. All the five-year

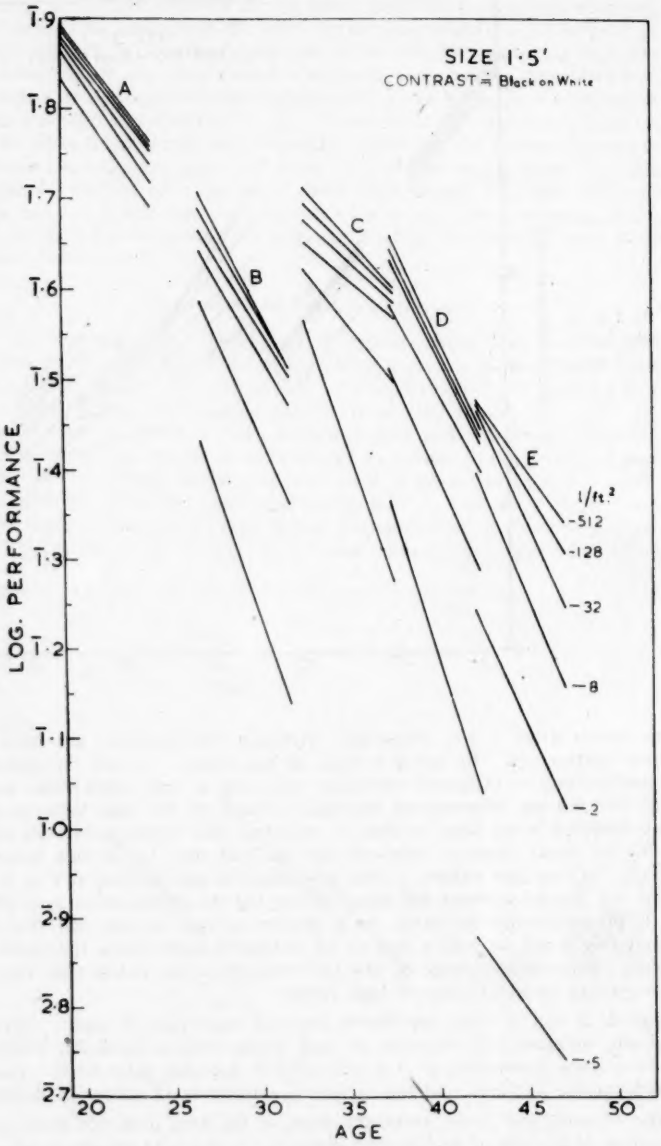

Fig. 4. As Fig. 2, but for tasks involving a size of 1.5 mins.

decline rates relating to the highest illumination used are represented separately in Fig. 5 so that they can be compared most readily.

The actual performance of each group plainly depends on its age and upon the illumination. The variation in performance produced by varying the illumination from 0.5 lm/ft.^{2} to 512 lm/ft.^{2} is small for the youngest persons, even when the task is the perception of very small detail; the variation, similarly produced, becomes progressively greater for the older groups and it also depends on the size of detail, being very great in the case of the oldest persons with the 1.5-min. task.

Besides the decline of each group as it advances in age, it is apparent from Figs. 2,

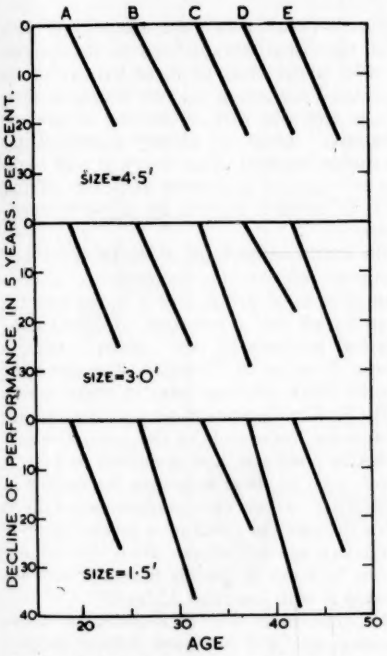

Fig. 5 *(above)*. Comparison of the five-year decline of performance of each age-group at the highest illumination.

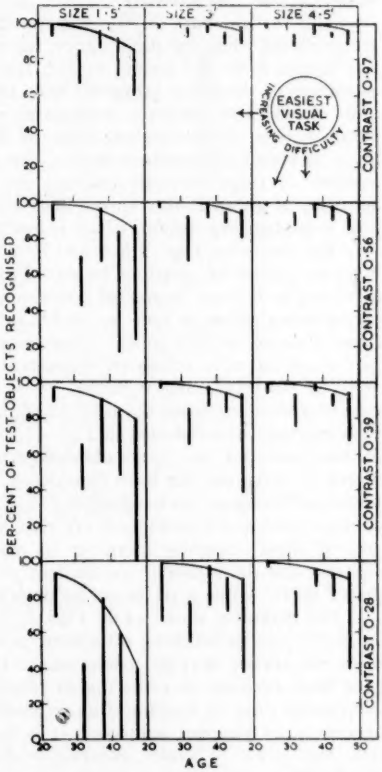

Fig. 6 *(right)*. The variation of accuracy of performance with age and illumination for tasks of different size and contrast.

3 and 4 that, (i) group B's performance is lower than group A's, (ii) that the performance of group C is also lower than that of group A, (iii) that D's performance is lower than C's and E's is lower than D's. Thus, the decline of performance with age is clearly indicated by the performances of the different groups, and consistently so in all the visual tasks. Only the fact that group B's performance is so much lower than group A's as to make it also lower than group C's prevents the performance rank of every group from corresponding with its age rank.

The disproportionately low performances of group B are mainly due to low accuracy scores, and this cannot be accounted for by any ocular defects in the members

of this group but appears, rather, to be due to the direction of their efforts towards quantity of "output" even at the expense of quality.

In Fig. 6 the groups are compared on the basis of accuracy alone, and it is easily seen that, in most of the visual tasks, including a number which are not covered by Figs. 2, 3 and 4, the accuracy of group B is lower than that of younger and older groups. Though the accuracy of this group, like that of the other groups, varies with the objective variables which determine the difficulty of the visual task, it is anomalous even when the task involving the largest size and best contrast is done at so high a level of illumination as 512 lm./ft.[2] It seems unlikely that any higher illumination would abolish this anomaly.

The vertical bars in Fig. 6 show the limits between which the accuracy of each group varied when the illumination for each of the visual tasks defined on the diagram was varied from 0.5 lm/ft^2 to 512 lm/ft^2. The upper ends of these bars (with the exception of those for group B) have been joined by drawing smooth curves to show quite clearly how accuracy depreciates with age, and also with diminution of size and contrast, even at the highest level of illumination. Since, as already explained, the index of visual performance used in this paper takes account of accuracy as well as the number of rings correctly marked per unit of time, it is evident that the inferior accuracy of group B must throw them out of rank unless it is offset by an exceptionally high score for rings found, which is not the case.

The diagrams, Figs. 7, 8, 9 and 10, show the results of the later of the two investigations on which this paper is based. Each diagram refers to the performance of tasks involving a different degree of contrast and three sizes of detail, and it shows how the performance of each task by each age group varied for a variation of illumination from 2 lm/ft^2 to 512 lm/ft^2. The cross-hatched portions of the "pillars" refer to performances with values of illumination from 2 lm/ft^2 to 32 lm/ft^2 (the geometric mean of the total range covered), while the solid black portions refer to performances with illuminations from 32 lm/ft^2 to 512 lm/ft^2. Fig. 7 combines in a single diagram the performance values plotted in Figs. 2, 3 and 4 at the lower ends of the group five-year decline lines, but the results obtained with inferior contrasts, and presented in Figs. 8, 9 and 10, have not yet been considered. From each of these diagrams the decline of visual performance with advancing age is apparent. At all ages performance falls as contrast, size and illumination are reduced, but the adverse effect of a given change in any of these variables increases in magnitude as age advances. With the poorest contrast and the smallest size the task could not be done by groups B and D with less than 8 lm/ft^2, while it could not be done by group E with less than 32 lm/ft^2.

The diagrams show, as do Figs. 2, 3 and 4, that increments of illumination above 32 lm/ft^2 give diminishing returns of performance, but, with the most difficult tasks, it does not appear that the performance of the oldest subjects at 512 lm/ft^2 could not have been bettered at some higher illumination. Nevertheless, any possible improvement could only be small and quite insufficient to make their performance equal to the maximum of younger subjects. It is interesting to note that with the most difficult task, viz., size = 1.5 min., contrast = 0.28, raising the illumination from 32 lm/ft^2 to 512 lm/ft^2 improves the performance of the youngest subjects by about 20 per cent. but increases the performance of the oldest subjects fourfold (see Fig. 10); when the contrast is very good, similar increments of performance are given by an increase of illumination from 0.5 lm/ft^2 to 512 lm/ft^2 (see Fig. 4).

It may also be noted that, with the highest illumination, the performance of the best contrast 3-min. task by subjects aged 47 is no better than the performance of the poorest contrast 1.5-min. task by subjects of about half this age (compare Figs. 7 and 10). So that, with 512 lm/ft^2, the 47-year-old subjects should perform the 1.5-min. tasks almost as well as the 24-year-old subjects do with the same illumination, the older subjects would have to be assisted by glasses giving a magnification of × 3. This is to

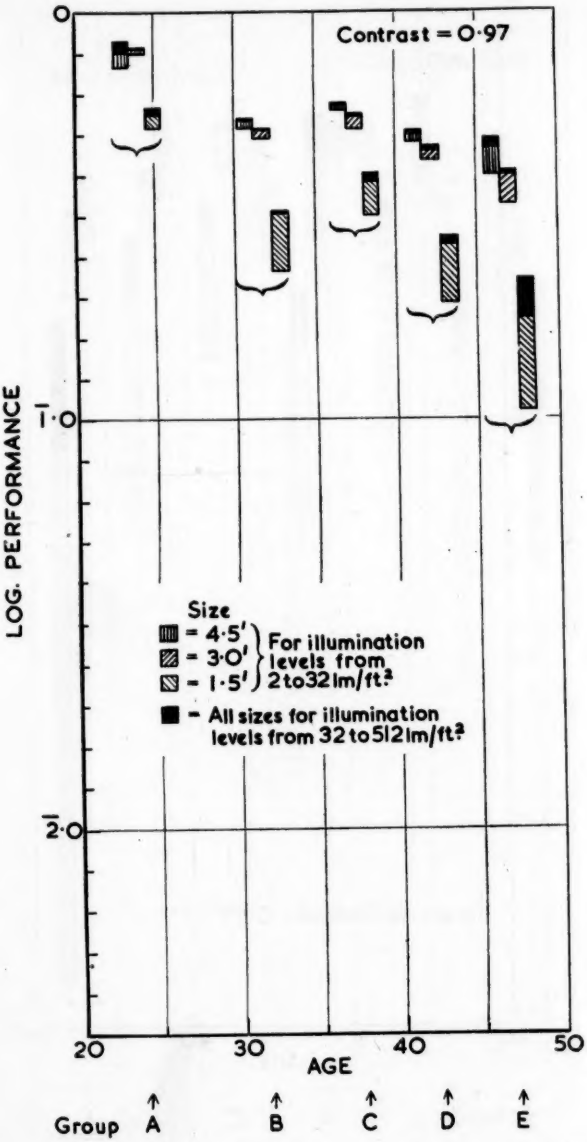

Fig. 7. Diagram for tasks involving the best contrast and three sizes of detail showing the variation of performance with age at illuminations from 2 lm/ft² to 512 lm/ft².

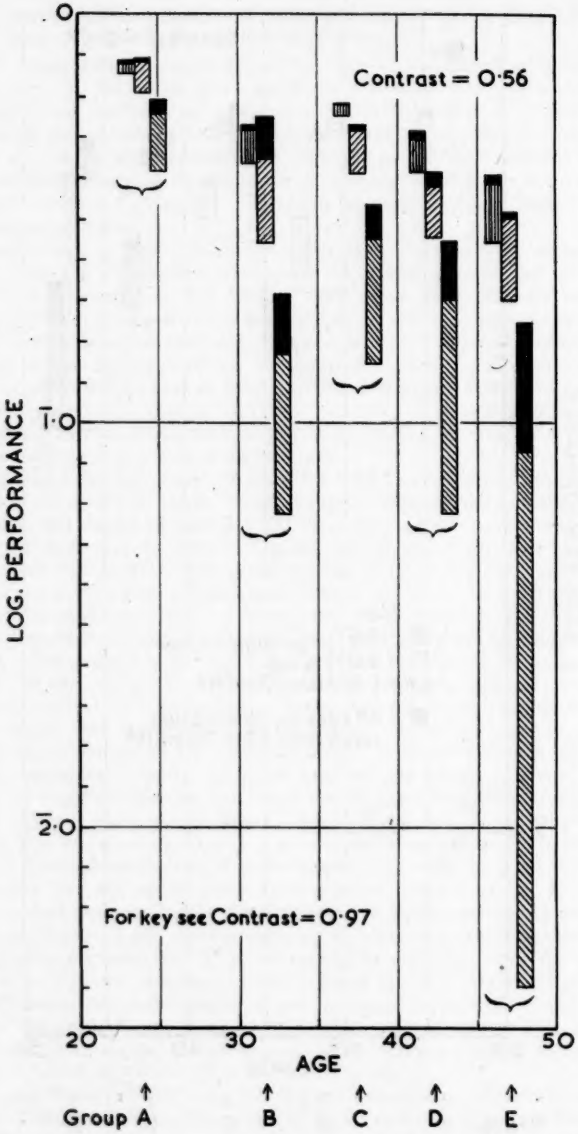

Fig. 8. As Fig. 7, but for tasks involving a relative brightness difference (contrast) of 0.56.

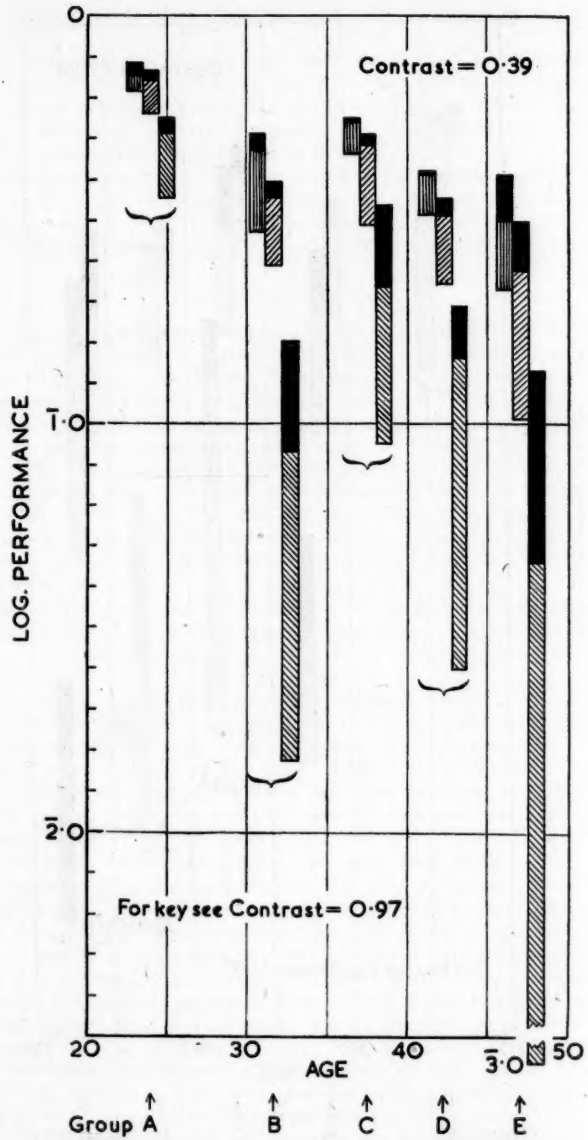

Fig. 9. As Fig. 7, but for tasks involving a relative brightness difference (contrast) of 0.39.

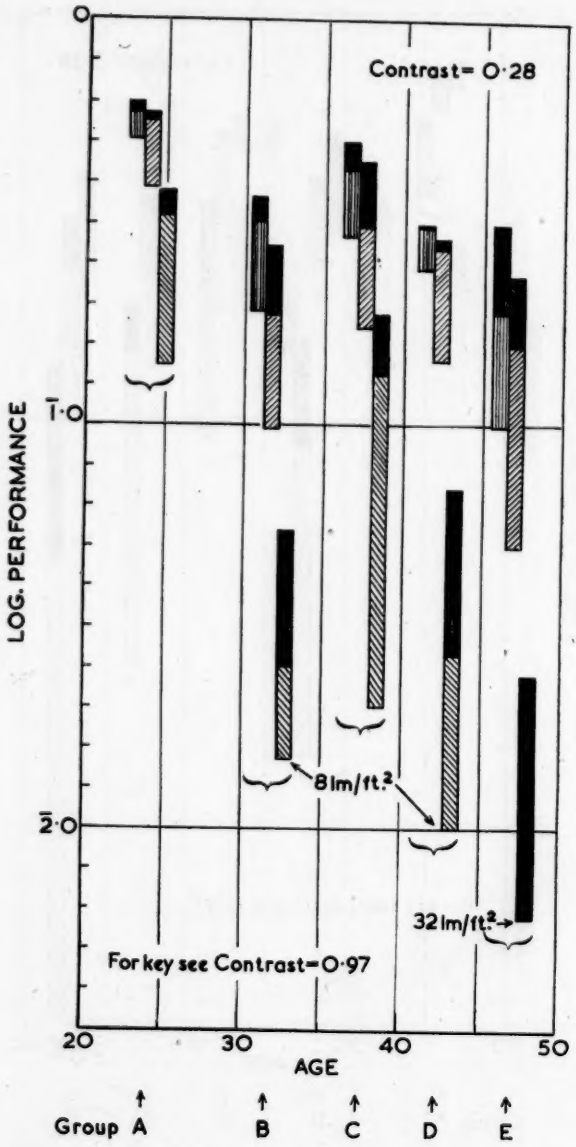

Fig. 10. As Fig. 7, but for tasks involving a relative brightness difference (contrast) of 0.28.

say that the 1.5-min. tasks must be made virtually 4.5-min. tasks, as can be seen from Figs. 7, 8, 9 and 10.

There is no illumination within the wide range explored at which the performance of all the test tasks does not decline as age advances; nor do the relations shown between illumination and performance for different ages give grounds for supposing that there is any level of illumination, however high, which would abolish the decline. So it follows that, although equal performance at every age might be obtained by using different illuminations according to age, the required performance could only be one within the capacity of the oldest persons considered, and the illumination provided for the younger persons would have to be low enough to prevent them from exceeding the standard performance; that is to say, younger persons would have to be handicapped.

The Rate of Decline

Because the groups were tested on two occasions separated by an interval of five years, the data obtained relate to ages covering a span of 28 years, making approximately the middle third of the total span of life. Also, as the interval between the two investigations corresponds approximately to the group to group difference of age, when each group was re-tested they had moved on to about the age which the next group in the series had when the first investigation was made, i.e., A_1 + 5 years = A_2 = B_1; B_1 + 5 years = B_2 = C_1 and so on. Thus, for certain ages, intervening between the limits A_1 and E_2 of the span considered, we know the performance of two differently constituted groups. From Figs. 2, 3 and 4, it can be seen that these different groups do not give similar performances when they are of similar age. Nevertheless, the means of their performances, at each level of illumination used, vary inversely with the ages to which they relate.

Taking the differences of the performances of the youngest and oldest subjects, who differed in age by 28 years, the average annual rate of decline during this period of ageing is found to be about 3 per cent. for the 4.5-min. task, 3.6 per cent. for the 3-min. task, and 5.3 per cent. for the 1.5-min. task.

These rates are calculated from the performances obtained with a task contrast of black on white and with an illumination of 32 lm./ft.^{2} When the illumination is increased or decreased by the high factor 16, the decline rates fall or rise accordingly, and to an extent which depends on the size of detail. Thus, when the illumination is raised to 32 × 16 lm./ft.^{2} the decline rates for tasks involving the sizes referred to above, become 2.8 per cent., 3.6 per cent. and 4.7 per cent. respectively. On the other hand, when the illumination is reduced to 32/16 lm./ft.^{2} the corresponding decline rates are, 3.8 per cent., 4.1 per cent. and 7.2 per cent. respectively.

For the shorter span of 16 years between the ages of 26 and 42, rates of decline can be derived from the means of the performances given by two different groups when they were of the same age, that is to say, from the means of the performances of groups A, B, C and D in the second investigation when paired with groups B, C, D and E in the first investigation. Inasmuch as these pairs of groups contain twice as many individuals as the single groups, it may be that the mean performance of each pair is more representative of the "average person" of corresponding age than is the mean performance of a single group. Rates of decline derived in this way are found to be lower than those already given. Thus, for the 4.5-min. task at 32 lm./ft.^{2}, the rate is 2.4 per cent., instead of 3 per cent.; for the 3-min. task it is 2.8 per cent. instead of 3.6 per cent.; and for the 1.5-min. task, the rate is 3 per cent., instead of 5.3 per cent., up to the age of 37 years after which it becomes much higher, viz., about 9 per cent.

The annual rates of decline found for each group from its own chronologically different performances are about 4 per cent. for the 4.5-min. task, about 5 per cent. for the 3-min. task, and also about 5 per cent. for the 1.5-min. task in the cases of

groups A and B, while it is 4 per cent. for group C, 8 per cent. for group D, and 6 per cent. for group E.

Evidently, although the data discussed provide factual evidence that visual performance of tasks of the kind described declines from early adulthood through the middle third of the life-span, they are not sufficient to enable the course of the decline during this period to be plotted precisely.

It cannot reasonably be supposed that if all the groups could have been tested at the same age their performances would have been equal. Almost certainly, between such small and unselected groups there were some differences of visual ability unrelated to age. Therefore, it cannot be assumed that the values of performance we have for different ages distributed over the middle third of life are so typical that it is justifiable to fit a single curve to them. It is more likely that each group has its own characteristic decline curve having its origin at a performance level differing somewhat from that of the other groups. This is strongly suggested by the disposition of the five-year segments plotted in Figs. 2, 3, and 4, though the separate group decline curves cannot be constructed by extrapolation on the basis of these fragments. On the whole, the evidence available suggests that, except for the task involving the smallest size, the decline of visual performance during middle life does take place at a fairly uniform rate, but that the decline for the most difficult task accelerates after the age of about 35. The decline rates assessed by different methods, as described above, indicate ranges within which it seems likely that the true average rates of decline lie; more than this it does not seem possible to say.

Chronologically different performances of the tasks involving inferior contrasts were not obtained, so decline rates for these tasks cannot be assessed in the same ways as those for the black and white tasks. However, it is easy to see, from Figs. 8, 9, and 10, that the rates given for the good contrast tasks are much exceeded when the contrast is degraded.

Other Evidence

The conclusion that visual efficiency declines from early adulthood may excite some surprise, and even scepticism, for a decline is popularly associated with a substantially later age when people with normal sight commonly resort to glasses for reading. Such glasses are needed to compensate for a decline in the amplitude of accommodation, which proceeds continuously from a very early age (see Fig. 11)

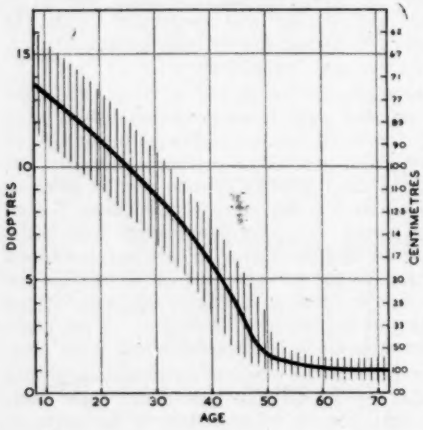

Fig. 11. Variation of amplitude of accommodation with age, according to Duane. The shading indicates the spread of normal values.

and has gone so far by the forties that we can no longer see near objects very distinctly with the unaided eyes. This is only one example of a decline which begins earlier than we who experience it suspect. Various investigators—Quetelet (1835), Galton (1884), Ufland (1933), Broch (1939), and others—have shown that muscular strength declines from the middle or late twenties onwards. It has also been shown that the speed of manual motility declines, and hand and foot reaction times increase, from about the age of twenty (2). Though less specific as to the age of commencement of decline, Galton's remarks on age and hearing are worth quoting for their salutary reminder that we are generally unaware of any impairment of capacity till it becomes considerable and is forced to our notice by some disconcerting event. "On testing different persons," he says, "I found there was a remarkable falling off in the power of hearing high notes as age advanced. The persons themselves were quite unconscious of their deficiency so long as their sense of hearing low notes remained unimpaired. It is an only too amusing experiment to test a party of persons of various ages, including some rather elderly and self-satisfied personages. They are indignant at being thought deficient in the power of hearing, yet the experiment quickly shows that they are absolutely deaf to shrill notes which the younger persons hear acutely, and they commonly betray much dislike to the discovery" (3).

As to visual functions, in addition to the changes in the lens which result, as already mentioned, in a steady decline of accommodative power from a very early age, variation in the colour of the lens modifies the colour sense as age advances. According to Hess (4) increasing yellowness of the lens causes, by the age of 25, a loss of 21 per cent. in transmission of the blue rays of daylight. He gives the loss at 45 years as 25 per cent., at 55 years as 66 per cent., and at 66 years as 75 per cent. Recent measurements by Crawford (5) have shown the loss of sensitivity to light of $\lambda = 0.42\ \mu$ as age advances. Relative to sensitivity at the age of 19, he finds a decline of 10 per cent. by the age of 32, of 20 per cent. by the age of 41, and of 30 per cent. by the age of 50. This gradual loss of sensitivity for blue is not noticed by the affected persons, and Hess advanced it as an explanation of the excessive blueness observed in the late works of painters, and it is also known that elderly silk-dyers tend to use too much blue in mixing their colours.

Bouma's (6) recent measurements of contrast sensitivity at a low adaptation level show that this function declines throughout the age range to which the present paper refers. The visual field of the dark-adapted eye has been found by Mann and Sharpley (7) to be maximal between the ages of 20 and 30 and to contract thereafter. Recently, also, Sharpley (8) has confirmed the fact that rod sensitivity declines (the rod threshold increases) continuously from adolescence onwards.

The rise, as age advances, in the level of illumination required for a given degree of visual acuity has been studied by Ferree, Rand and Lewis (9), some of whose data are plotted in Fig. 12. Much of the age range with which we are here concerned is covered by their observations, and it follows from these that if illumination is held constant visual acuity declines as age advances from the twenties onwards. Incidentally, the difficulty of assessing occupational visual fitness only from acuity scores is brought out by consideration of Fig. 12. It can be seen that, at an age corresponding to the mean age of our oldest subjects, the acuity found by Ferree and Rand at moderate illuminations was much higher than was required for perception of the smallest detail in the experimental tasks considered in this paper; yet, even with much higher values of illumination, our oldest subjects could not perform the 1.5-min. task nearly so well as the youngest subjects did with an illumination low enough to make them (presumably) inferior in acuity.

It is well known that the physiological size of the pupil diminishes with advancing age. This naturally reduces the brightness of the retinal images of external objects,

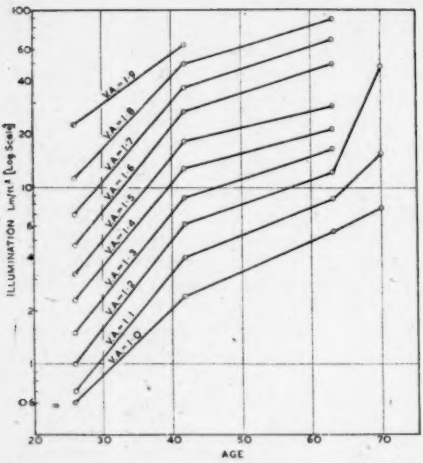

Fig. 12. Variation of illumination with age for different degrees of visual acuity. (Ferree, Rand and Lewis.)

but, on the other hand, it has the effect of sharpening the images, since aberrations due to the more peripheral zones of the refracting media are avoided. The size of the pupil is affected by many factors, and the variation of average size with age is not easy to ascertain. Over the age range we are considering, this variation is certainly not great (perhaps in the ratio of two to one), and to vary illumination in inverse proportion to pupil area would not equalise the visual performance of persons at the extremities of this range.

Visual performance is not, of course, determined by ocular factors alone, but is the outcome of mental activity. The visual system proper includes not only those parts of the brain which are housed within the eyes (i.e., the retinæ), but the optic pathways and the visual area of the cerebral cortex. These nervous structures, and other parts of the brain that are involved in any act of cognition, are subject to demonstrable physical and chemical changes with age which underlie changes of human behaviour. And, if the observed deterioration of visual performance cannot be accounted for adequately by ocular changes, to invoke a psychological explanation amounts to no more than a reference back from end-organ to central organic changes.

Conclusion

So far as specific performances are concerned, we have no grounds for believing "middle life" to be a kind of plateau intervening between the ascent to full capacity and the decline which, sooner or later, is inevitable. Science has not yet given the lie to the moralising fool of the Forest of Arden—"And so, from hour to hour, we ripe and ripe, and then, from hour to hour, we rot and rot." * But, we choose our norms on the basis of average individuals, and, for visual performance, we should regard as normal the performance attainable by persons of average vision and average age. Occupationally, "average age" means about 35 years, and it is on the basis of performance at about this age that the present I.E.S. standards of illumination are fixed. The age distribution of the population is changing, and the average age of persons "gainfully employed" is advancing but is unlikely to go far enough for a radical change of illumination levels to be called for on this ground

* "As You Like It." II, vii.

alone. It appears that, with really difficult visual tasks, any attempt to raise the performance of persons above average age more nearly to the level attainable by persons below average age calls for individual lighting giving high levels of illumination. There is no doubt whatever that as age advances higher levels of illumination mitigate its handicap. Even so, more is to be expected from optical aids—not merely for countering the recession of the near point, but for enlarging the visual objects.

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